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NATIONAL BUREAU OF STANDARDS REPORT

10 484

CORRIDOR PROGRAM STATUS REPORT I

Sponsored by:

Department of Health, Education and Welfare



U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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CORRIDOR PROGRAM STATUS REPORT I

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U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

CORRIDOR PROGRAM STATUS REPORT I

Abstract

An interim status report of the corridor fire program is presented. The program is concerned with the spread of fire in corridors, built with different flooring and ceiling materials, cross-section aspect ratios, ventilation conditions and energy inputs. Flooring materials tested so far have consisted of acrylic carpet with and without pad, oak flooring, vinyl tile and masonry. Ceiling materials tested are gypsum and particle boards.

Test by test descriptions are provided and observations are supplemented by temperature, velocity and radiometer measurements. Based on the tests conducted limited qualitative conclusions are presented while further data reduction and analysis are still in progress. The report concludes with detailed recommendations of feasible theoretical approaches and additional instrumentation to supplement and improve the present test program.

CORRIDOR PROGRAM STATUS REPORT I

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CORRIDOR PROGRAM STATUS REPORT I

1.0 INTRODUCTION

This investigation is concerned with the spread of fire in corridors, built with different floor and ceiling materials, cross-section geometries, ventilating conditions and energy inputs. Flooring materials have consisted of carpeting, oak flooring, vinyl tile and masonry. Tests have been carried out under natural convection and forced convection conditions.

There are a number of possible approaches to the examination and description of the corridor fire. One is a qualitative description of the events occurring in the corridor during fire buildup and finally at flashover. This approach has been used by Waterman and coworkers^{1,2} in studying various aspects of room fires including furniture. For fire buildup in rooms having only natural convection he concluded the following:

1. During fire buildup in a residential size room having noncombustible and moderately insulated walls and ceilings there are two rather distinct homogeneous gas layers which are separated by a horizontal plane, corresponding with the

neutral-density plane of the opening where air moves in below and gases move out above the plane. Further, temperature and gas concentrations are relatively constant within each layer but change rapidly in the immediate vicinity of the separating plane. He believes this conclusion is not valid for the space immediately above the burning item nor for large floors or low ceiling.

2. The combustible gases distilled from unignited items rise only to the neutral density plane where they spread and flow out of the window.
3. That O_2 and CO_2 concentrations within the room are quite dependent on the ratio of ventilation opening to burning rate; while the CO concentration has no such direct dependence but is only noted to increase sharply when ventilation is quite restricted.
4. That radiant energy transfer measured at various room locations is due to the hot walls and ceiling and is not primarily from the flames.

For the phenomena of flashover Waterman concluded the following:

1. That room flashover is the rapid involvement of the many items of combustible room contents where their ignition energies are exceeded nearly simulatenously: These energies depend on the

rate of heating and composition of available air (mainly O_2 concentration).

2. That room confinement, not the high concentration of unburned combustibles near the ceiling is the cause of nearly simultaneous exceeding of all ignition energies. The measured concentration of unburned combustibles near the ceiling were well below flammability limits.
3. That major furniture items usually initiate room flashover in the room size investigated.

This qualitative approach to room fires with furniture can aid in describing our corridor fires during fire buildup and at flashover, particularly in the case of natural convection.

A second type of approach to describing corridor fires is a quantitative description of heat gained or loss by the corridor in its various regions, during fire buildup and possibly at flashover, using heat balance principles.

Various approaches have been applied to either rooms, ducts or corridors using the heat balance principle some of which are:

1. The semi-empirical heat balance analysis of the corridor during the fire by knowing the heat input to the corridor and that lost by convection; and the losses due to conduction by the corridor surfaces, knowing the surface temperature and conductive

characteristics of the walls, floor and ceiling of the corridor as a lump system. One simple treatment of this type has been done for the behavior of fire in an enclosure by Tsuchiya, Y. and Sumi, K.³ Another more sophisticated treatment was done by Kusada⁴ and coworkers to predict the transient indoor temperature response by use of stochastic methods.

2. Another method is to divide the room corridor or duct into zones or cells and do a simplified heat balance of these regions where steady-state can be assumed to be applicable. Such an approach has been applied to a long corridor by Roberts⁵ and coworkers. The mathematical representation of which has been further refined by DeRis, J.⁶ A more detailed discussion on the possibilities of various theoretical approaches are included in this report under section 4.0.

2.0 TEST SUMMARY

2.1 Introduction

The objective of this program is to conduct full scale tests to define and quantify the fire related characteristics of corridors, with particular emphasis on the study of the fire hazards generated. This information will then be used to provide means for determining the merit of existing laboratory tests and their relation to the fire hazard, to provide physical insights for predicting performance, and to serve as an invaluable data source for developing further understanding of fire spread.

The initial test plan considered as essential variables: floor finish, carpeting, underlayment (pads), substrata; walls and ceiling finish, corridor dimensions and geometry; burn room fire load, ignition source and burning rate; corridor air velocity; initial temperature and initial relative humidity.

Test facilities and instrumentation will be described in a separate supplementary document.

Of primary concern during the first exploratory series, now being conducted, are the variations in floor and ceiling coverings and the air velocity in the corridor. This initial series is exploratory to determine the locations and types of instrumentation needed. This work is also expected to provide us with information leading to the improvement of instrumentation and the development of analytical procedures.

2.2 Initial Test Work

The tests commenced with a series of wastebasket tests, the objective of which was to obtain knowledge of the burning behavior of minor fires and to develop a standard minor fire exposure.

After this, crib tests were carried out in the "burn" room adjoining the corridor. For all of these tests the corridor walls and ceiling were of 5/8 inch gypsum board backed with fiberglass insulation and floors were brick lined. These tests progressed from one to three cribs each weighing about 20 pounds.

2.3 Corridor Tests (Test Variations)

The initial work in the burn room provided information regarding placement of instruments such as thermocouples, radiometers and load cells. Additional crib material was then added in the form of three double weight cribs varying in weight from 114 lbs to 133 pounds.

At this time ceiling materials possessing varying flammability characteristics were added to the corridor. These included fiberboard ceilings having flame spread indices of 30 and 136 by the E162 test procedure. Also used was a combination of materials with the first eight feet having an index of 136 and the remaining having an index of 30.

Later tests, including those presently being conducted, have made use of a particle board ceiling having a flame spread index of 120. Carpeting on the floor has a flame spread index ranging from 145 without a pad to 150 with a pad.

2.4 Discussion of Test Results

Summary of the prime variables used in each test along with some observations are presented in Table 1.

2.4.1 Fire Load

The maximum total crib load used in these tests was 172 pounds. The load per unit area in the 7 ft. 9 in. by 8 ft. 4 in. room becomes 2.7 lb/sq. ft. (13 kg/m^2). This is considered to be a low fuel load per unit area. In work by Baldwin et al the authors' summary refers to an average of 20 kg/m^2 (4.1 lb/ft^2) and the 95 percentile of 59 kg/m^2 (12.1 lb/ft^2) for the buildings surveyed and adds, ".....these buildings would thus be regarded as having a low fire-load."

2.4.2 Burning Rates in Burn Room

The burning rates of real life fire loads may be lower than the rates of the cribs used in the tests, at least if the earlier stages of combustion are compared. A comparison of load cell data curves shows that the peak heat release for three cribs ranges from a low of 39,900 Btu/min to a high of 71,700 Btu/min^{*}; and for four cribs the release rate varied from a low of 38,900 Btu/min to a high of 127,600 Btu/min. Figures 1 and 2 are burning rate comparison plots.

Real life combustible loadings have not yet been tested. The objective of the burn room fire loading has been to establish a low heat source sufficient to start ignition of the floor covering but not so large that

* See Appendix A.

it would mesh the contribution of each of the corridor combustibles to the total fire hazard picture. Tests of real life furnishings in the burn room can be conducted at a later date.

2.4.3 Preliminary Tests

Tests 321-323

The initial tests, tests 321 through 323, were carried out primarily to standardize instrumentation procedures, and to have data available for later comparisons when combinations of variables were to be tested. Thus information was collected to answer the question of how would one, two or three cribs burn with a non-combustible floor and ceiling.

Tests 324-329

Tests 324 through 329 added ceilings of varying flame spread, as determined by the ASTM E162 Radiant Panel Test. As in the earlier tests, thermocouples, radiometer and heat flux meter data was collected for comparisons with later tests. In the last test of this series, test 329, carpet patches were added to the floor. The burn room fire load was also increased to four cribs (25 percent more weight than in any previous test). As shown in the Corridor Test Summary Table, the peak floor radiometer value was almost twice as great for this test as for test 325, a test using a higher flame spread ceiling. Two comments are suggested by this comparison:

1. A blank test should be run with four cribs and with only the brick floor and gypsum board on the walls and ceiling to

investigate the possibility that the fuel load was increased by too great a factor to bring out the difference between the effects of varying walls, ceiling and floor construction.

2. The peak radiometer values, peak temperature values, as well as rates of change of these values, may be of value to the studies of the relative effects of different materials.

Up to test 329 air for the fire was supplied by an air conditioning system, supplying air at 75 °F and 30% relative humidity through a perforated wall at the burn room end of the corridor.

Tests 330 through 333 used no forced air. These tests all made use of the same brown acrylic carpet (referred to as Sample No. 1) with a rubberized hair felt pad. Motion pictures were made of all these tests.

Test 330

Test 330 made use of Sample No. 1 carpet, installed wall-to-wall and a particle board (chip board) ceiling. The walls were gypsum board. The fire spread from the burn room to the corridor within 2-1/2 minutes after ignition. The fire spread throughout the 30 ft. length of the corridor in approximately one minute. Flames about 18 inches high were observed to spread down the carpet surface. The carpet fire was confined almost completely to the surface pile. A short distance outside the fire room door the combustible pad and the carpet backing was unaffected. The

dense black smoke through the test was judged to have developed lethal conditions.

Test 332

Test 332 made use of the same ceiling and wall material as test 330 but omitted the carpet and pad. In this case ignition of the ceiling was much slower (9 min, 20 sec as compared with 2 min, 55 sec and the smoke density much lower.

The following tests are described in more detail as more instrumentations became available for documentation of results.

Test 333

Test Conditions

In test 333 gypsum board ceiling and walls were used and had been painted with a fire retardant paint. Four wood cribs totaling 172 lbs. were used. The floor material was a brown acrylic rug with a rubberized jute pad covering the whole corridor floor. Air flow was by natural convection.

Observations

(a) Air Flow

The air velocity at the top of the burn room door varied from 0 to a maximum of 994 ft/min during the test while that at the top of the exhaust window varied from 0 to 1144 ft/min. The inflow of air at the bottom of the exhaust window was a maximum of 560 ft/min when out flow at the top of the window was a maximum at 11.6 minutes after ignition.

Between 5 and 6 minutes after ignition the carpet in the burn room burned causing a dense smoke cloud in the corridor by 6 minutes.

At approximately 6 minutes a large flame plume extended out of the burn room across the ceiling and by 6.25 minutes extended in depth nearly to the floor from the corridor ceiling back near the burn room. During this period of flame pluming, the velocity reading at the top of the burn room door reached its maximum of 994 ft/min while the velocity at the middle of the burn room door was only 450 ft/min, still 350 ft/min below its maximum. The outflow velocity at the top of the exhaust window was only 600 ft/min. The air near the ceiling rose rapidly to approximately 400 °C

at the 15 ft. station during the flame pluming phase. While ceiling surface temperatures at the 2.5, 5, 10 and 15 ft. stations were 600 °C, 525 °C, 325 °C and 300 °C indicating that the flame plume extended approximately 5 to 8 feet down the corridor.

(b) Carpet Temperatures

The carpet surface rose to approximately 220 °C as the flame plume extended down near the floor. However carpet flaming did not occur until the period between 7.5 and 8 minutes in the area extending approximately 10 feet down the corridor from the burn room as the rug surface temperature at 2.5 and 7.75 feet had reached between 250 and 300 °C at 8 minutes. This concurs with visual observations (See Table 1) that the carpet surface temperature at the 22 feet did not reach this temperature until 10 minutes indicating the flame required approximately 2 minutes to progress to the 22 foot station from the time of first observation of carpet flaming at 7.75 minutes. The ignition of the carpet resulted in a rapid rise in the air temperature between 9 and 10 minutes to approximately 900 °C which was uniform in the air near to the floor at the 15 foot station.

The air velocity in the exhaust window continually increased toward the maximum values during the period of carpet combustion which extended the entire length of the corridor reaching the window at 11.66 minutes at which time the exhaust velocity readings were a maximum but the air temperature in the middle of the corridor had begun to decrease from its maximum of 900 °C which occurred at 10 minutes.

Test 337

Test Conditions

The test conditions were gypsum walls and ceiling with brown acrylic carpet (same as previous test) on top of transite flooring (no carpet pad). Like test 333 draft condition in the corridor was by natural convection and again four wood cribs averaging 40.5 lbs each provided the energy source from the adjacent burn room. Thus the only initial difference between test 333 and 337 was the lack of carpet pad in test 337.

Observations

Again like in previous test there was a transient supply of heat to the corridor from the burn room which is believed to approach steady-state conditions in the corridor after 7-8 minutes. This appears to be supported by the air temperature readings in the burn room door which stabilized after this time.

(a) Corridor Ceiling Temperatures

Between 5 and 6 minutes the ceiling gypsum paper ignited in the upstream half of the corridor as indicated at the 10 foot station by the rapid rise of the surface T/C temperature above that in air 1 foot down. The ceiling surface temperature reached 250-300 °C at the 5 foot station after 5:00-5:25 minutes while the 10 foot station did not reach this range until 5.5 to 6 minutes after ignition while the 20 foot station did not reach the temperature range until after 7 minutes. This supports the observation of the gypsum paper ignition in the upstream half of the corridor being between 5 and 6 minutes. This paper burning represents a short duration

transient energy source of approximately 1 minute duration prior to carpet ignition.

(b) Carpet Temperatures

In the period beginning between 6-7 minutes the carpet in the burn room ignited introducing dense smoke in the corridor. At 7 minutes the carpet ignited near the burn room as indicated by the upstream floor T/C at 2-1/2 feet, 1 inch up in air. This is also supported by the fact that the carpet surface temperature at 2.5 feet at that time rose to 300 °C. On the other hand the carpet surface temperature at the 7.75 foot station reached only a maximum of 160 °C to 200 °C where it remained through most of the remaining test time. This supports the visual observation that carpet flaming progressed only to the 6 to 7 foot distance while severe scorching occurred up to 12 feet.

The above mentioned carpet flame progression was a transient short duration energy source (2 minutes duration) heating the air rapidly in the corridor as indicated by the 10 and 20 foot air strings and extended the heating effects down 7 feet from the ceiling at the 20 foot station, while the floor remained a cool 50 °C. This transient floor burning, as usual, caused depletion of O₂ in the corridor and burn room resulting in a reduced temperature in the time range 8-11 minutes causing the corridor air temperature to drop below their base temperature (due only to steady-state burn room heating of the corridor).

After 11 minutes the corridor temperatures returned and remained at their

steady-state temperature readings due to the steady-state burn room heat supply only, since carpet no longer burned.

Comparison of Test 333 and Test 337

It is noted that the only physical structure difference between test 333 and 337 is the addition of carpet pad in test 333. It is further observed that in both tests 333 and 337 that the corridor carpet ignition began around 6 minutes with 333 being the earlier ignition time.

(a) Corridor Ceiling Temperatures

The corridor ceiling surface temperature at the 5 ft. station had just exceeded 400 °C at the time of initial corridor carpet ignition in both tests. However in test 337 the ceiling surface temperature at the 5 foot station remained between 400-500 °C only to fall below 400° at 10 minutes but again later rose to a maximum of 500°. But the ceiling surface temperature at the 10 and 20 foot stations never reached 400 °C during test 337. In contrast, in test 333 the ceiling surface temperature rose rapidly above 400 °C after corridor carpet ignition to a maximum of 630 °C where it remained until carpet flames propagated to the exhaust window at 11.66 minutes. Also in test 333 the ceiling surface temperature at the 10, 20 and 25 foot stations all rose rapidly above 400 °C between 8.8 and 9.2 minutes to a maximum of 700 to 750 °C where they did not fall below 600 °C until flame propagated out the exhaust window. This may imply that when the ceiling temperature exceeds 400 °C that the radiant energy may supply enough energy to sustain propagation of the carpet flame front. As to whether the ceiling can maintain a uniform surface temperature above 400 °C for the duration of

the test probably depends on the rate of heat supplied by the burn room initially and the level of heat supplied by the burn room after steady-state is reached.

(b) Burn Room Ceiling Temperatures

It is noted that the crib load cell became defective in test 333 therefore test 333 can not be compared to test 337 as to amount and rate of heat supplied from burn room based on crib weight. But it is noted that the burn room ceiling temperatures in the case of test 333 as shown in Figure 3 rose rapidly between 4 and 6 minutes after ignition to maximum above 800 °C and remained above 700 °C for the duration of the test but in the case of test 337 the burn room ceiling temperature readings rose much more slowly between 4 and 8 minutes after ignition and even more slowly to steady maximum values between 550 and 670 °C after 14 minutes. This is reflected in lower ceiling surface temperatures and lower convective energy from the burn room in test 337; which would be important in the lack of sustained flame propagation in test 337.

(c) Carpet Temperatures

It is observed that the backup T/C between the carpet and pad at the 2.5, 7.75 and 22 foot stations progressing from the burn room to the exhaust window gave rapidly rising temperature reading to sustained values in excess of 400 °C as the flame progressed over that respective station. This contrasted to the backup T/C temperature readings between the carpet and transite in test 337 at the 2.5 and 7.75 foot stations as the flame progressed over them, of less than 100 °C indicating that the pad reduced

heat loss in the vicinity of the flame front in test 333 thus more heat retained in the area of the flame front by the insulating pad, the more able the flame is to propagate down the carpet in accordance with diffusional flame theory.

Discussion

Thus it appears there are possibly at least two factors to explain the sustained flame front observed in test 333:

1. Higher radiant energy to the flame front from the ceiling and upper walls.
2. A reduction in energy loss in the flame front due to the pad insulating effect.

Test 335

Test Conditions

The conditions used in this test were gypsum walls and ceiling with a varnished oak floor. Again like the previous test in this series the draft condition in the corridor was by natural convection. The four wood cribs providing the heat source from the burn room, weighed an average of 43 lbs each. Therefore, the only difference between this test and tests 333 and 337 is the varnished oak flooring as opposed to carpet.

Observations

(a) Burn Room Ceiling Temperatures

In the initial period after ignition there was a very rapid increase in the transient supply of heat to the corridor from the burn room. The burn room ceiling temperature rose to a maximum of 830 °C in 6 minutes from ignition. This is comparable to the heating rate of test 333 in the same period while test 337 only reached 350 to 400 °C in that same initial period. In that period the maximum ceiling temperature rise rate $\frac{dT}{dt} = 400 \text{ }^{\circ}\text{C/min}$ which is the same as that for test 333 but this is twice that of test 337. During the remaining portion of the test 335 the ceiling-temperature decreased to around 700 °C where it remained for the duration of the test. This is comparable to the burn room ceiling conditions in that period on test 333. As a result of this rapid burning, flames were noted to lick the corridor ceiling after 4 minutes. This resulted in ignition of the corridor ceiling gypsum paper and paint near the burn room.

(b) Corridor Ceiling Temperatures

During the period between 4 and 4.6 minutes in which flame pluming occurred, the corridor ceiling temperature at the 5 foot station reached the range between 250 and 300 °C at 4 minutes and climbed to a maximum 625° at 5 minutes. On the other hand the corridor ceiling surface T/C at the 10 foot station only reached 235 °C and 4 minutes and had only approached 250 °C at 5 minutes after ignition. This supports the observation that maximum flame pluming down the ceiling from the burn room occurred only to a distance of 6 feet along the ceiling at 4.50 minutes since the T/C

at the 10 foot station read 200-250 °C in this period. The fact that while combustion of the gypsum paper occurred in the area of flame pluming the ceiling gypsum paper burning did not occur in the area of the 10 foot station until after 5 minutes. This supports the observation that actual burning of the ceiling became visible at 5 minutes. The burning of gypsum paper and paint on the corridor ceiling was also indicated by the fact that the 10 foot ceiling T/C begins to rise rapidly in temperature above the T/C 1 foot down in the air at the same station.

(c) Floor Temperatures

The above burning of the ceiling reached a maximum between 5 and 6 minutes, after which the temperature in the corridor declined rapidly toward steady state values until the varnish on the whole floor ignited at 7-1/2 minutes with a rapid rise in air, floor and ceiling temperature until extinguishment (9 minutes). This varnish ignition produced a type of flashover. It is noted that the floor surface T/C at the 5 and 10 foot station exceeded 250-300 °C at 7 minutes and had reached 400 °C by 8 minutes after ignition but the floor surface T/C at the 20 foot station only reached 250-300 °C after 8 minutes. If the floor ignition time of 7-1/2 minutes in this test 335 is compared with the carpet ignition time of test 333 and 337, it is seen to occur in the same time range of 7-8 minutes after ignition.

Test 336

Test Conditions

This test attempted to duplicate the condition of tests 333, 337 and 335 except that the floor material in this case was vinyl tile. The four wood

cribs providing the heat source from the burn room weighed an average of 40 pounds.

Observations

(a) Burn Room Ceiling Temperatures

After ignition of the wood cribs the initial transient heat supply tended to remain low during the first 4 minutes after ignition, but rose rapidly between 4 and 7 minutes as indicated by the temperature changes on the burn room ceiling. The maximum temperature 500-800 °C of the burn room ceiling was reached after 8 minutes but the maximum rate of temperature rise occurred between 4 and 5 minutes after ignition. It was in this period between 4 and 5 minutes, that flames begin to lick the corridor ceiling surface from the burn room door (4.66 minutes).

Between 5 and 6 minutes a flame plume spread along the ceiling to 8 feet distance from the burn room. This was the approximate time of comparable observation in tests 333 and 337. The transient supply of heat from the burn room continued until it reached a steady-state relation to the corridor at around 7 minutes; this was indicated by the response of the air T/C in the burn room door and those on strings in the corridor.

(b) Corridor Ceiling Temperatures

The transient time indicated is in agreement with the time of transient heating in the previous test. It was noted that ceiling surface temperatures at the 5, 10 and 20 foot stations rose rapidly above 300 °C between 4 and 5 minutes and reached their maximum between 780-860 °C at approximately 8

minutes after ignition. The vinyl tile began to flame in the corridor at the 1 foot station at about 6.5 minutes.

(c) Floor Temperatures

The floor surface temperature at the 5 and 10 foot stations exceeded 300 °C at 6.8 minutes and 9.35 respectively after which they reached maximum of 700 °C at 10 minutes for 5 feet and 540 at 10.5 minutes for 10 feet. The floor temperature at 20 feet only reached 200 °C maximum during the test. These floor temperature observations support the observation that floor involvement progressed only to the 10 to 12 feet from the burn room. The ignition of the floor caused rapid transient heating of the air in the upper half of the corridor as indicated by the 10 and 20 foot string T/C's in the corridor. The air down to the 7 feet below the ceiling at the 20 foot station reflected the upstream floor burning.

Test 334

Test Conditions

In test 334 not only was a combustible ceiling material (chip board) in addition to a combustible floor material (brown acrylic carpeting with pad), the draft condition was that of force draft. Four cribs totaling 176 lbs were used.

Discussion of Draft Condition

In test 329 the draft condition was that of forced convection, but in that case there was no combustible floor material, but a combustible chip board ceiling. In test 329 the total length of the ceiling burned in 12 minutes

at which time a form of flashover was noted. On the other hand when a corridor test was carried out where the combustible chip board ceiling and the floor material was a brown acrylic carpeting with pad; then the floor and ceiling material being the same as test 334, but the draft condition was that of natural convection the results (test 330) being flame completely engulfing corridor by 4.00 minutes after ignition and only 45 seconds after initial flaming of the carpet in the corridor. It might be noted that in test 330 as well as test 334 that the burn room ceiling temperature rose at a lower rate than in test 333 and 335 as well as the maximum burn room ceiling temperature being lower. If one examines the results of test 329 and those of 330; one could conclude that in test 334 there should be a complete corridor involvement like test 330 but requiring more time like test 329. This is indeed what occurred.

Comparison of Tests 330 and 334

In test 330 flaming started on the corridor carpet after only 3.25 minutes while it required 5.5 minutes after ignition for this event to occur in test 334. It was noted that it required only 4 minutes to engulf the corridor in the case of test 330 while test 334 required nearly 10 minutes for this event. But it might be noted from the ceiling T/C that at the time of what appeared to be the first complete flame involvement of the ceiling and the carpet in test 330; that only the ceiling temperatures at the 5 foot, 10 foot and 20 foot stations attained the 250-300° range to reach maximum of 560 °C, 460 °C and 320 °C respectively at 4 minutes while at this time of flashover all the floor temperatures remained below 140 °C during this 4 minute period before initial attempt to extinguish. In

contrast in test 334, at 8-9.5 minutes where this flashover event occurred the ceiling temperatures rose rapidly to their maximum of 770, 670 and 390° at their corresponding stations 2.5, 5 and 20 feet at 9 minutes while the carpet surface T/C rose sharply above 300 °C to their maximum of 830, 630 and 350 °C at the 1.66, 7.66 and 22 foot stations at 9.5 minutes. As the time of total involvement of the corridor was approached in test 334 the center of exhaust window air velocity increased until it reached a maximum of 1096 ft/min at 9.4 minutes (near flashover time).

Discussion

Drawing on the limited comparisons between test 330 and test 334 one may conclude that as compared to natural convection fire added "forced-ventilation in corridor" tends to delay corridor involvement due to faster energy convection out the exhaust window. However, when fire does propagate and involve the corridor interior added "forced-ventilation in corridor" has the opposite effect of increasing fire intensity by "fanning."

2.4.4 Summary and Conclusions

From temperature data it appears that the corridor takes approximately 7 minutes after crib ignition to reach a steady-state heating condition with the 4-crib burn room as the only source of energy. It is further noted that the gypsum paper on the ceiling generally ignites after 4 minutes while the heat supply from burn room is still transient.

A combustible ceiling without combustible flooring may or may not burn all the way down the corridor depending on the ceiling material flammable index as indicated by tests 325 and 327.

Whether ceiling is combustible or not it is still the dominant heat transfer factor that will lead to corridor involvement. In both tests 330 and 333, the carpets were completely involved. In test 333 which had incombustible ceiling complete corridor fire involvement occurred later.

Without a combustible ceiling generally the floor material would ignite after about 7 minutes and the flames would spread less than half way down the corridor unless the heating supply rate was great enough from the burn room to cause the ceiling temperature down toward the exhaust window to become high enough to cause sufficient radiant energy reinforcement on the convection effect to cause the fire to involve the floor beyond 15 feet.

The pad behind the carpet appears to be an important factor in whether flame propagation over part or the whole carpet length due to the fact that

the pad retains the energy in the propagating flame vicinity once ignited.

When a combustible ceiling material was used with a carpet the whole corridor became involved, probably due to radiant energy interaction and reinforcement. When the area of floor nearer the window does not ignite it is noted that the floor temperature remains cool while air temperature up 1 foot from the floor rises rapidly upon additional energy supply.

A comparison of this brief test series shows the possible existence of a pattern in corridor ignition times but not necessarily in peak radiation values.

The most severe fires occurred in those experiments combining a combustible ceiling and carpet.

The fastest corridor ignition time (2-1/2 minutes) took place in test 330, which made use of a combustible ceiling and rug, with no conditioned air being supplied. However, the peak floor radiation value was 1.8 W/cm^2 , the lowest observed for the carpet tests.

When air was supplied in the form of an artificially created draft, as in test 334, the time for corridor ignition was approximately the same for the combined ceiling-rug hazard as for test 332 using only a flammable ceiling, but no forced draft. In contrast the peak radiometer value was 5.4 W/cm^2 for test 334, which is indicative of the severity of the last test.

Figures 4, 5 and 6 showing the times and values of peak floor radiation provide the same general information as the visual observations, i.e., the times at which the peak values occurred coincide with both the visual observations and thermocouple data.

The ceiling continues to be the predominant hazard when comparing a test using the combustible ceiling alone (Test 332) against a test having a relatively flammable carpet alone (Test 333). However, in every case the carpet runner leading into the burn room always generated heavy intoxicating black smoke at very early stages of the fire.

Thus it may be concluded that corridor involvement of energy release from its linings depends on the location of the lining (ceiling or floor); the ignition temperature of the lining (for example, gypsum paper will ignite more readily than chip board), degree of area involvement depending on convection pattern and amount of radiant energy reinforcement. Thus due to different times of involvement of various areas of corridor, the corridor fire may be divided into different phases depending on the source of combustion energy release in the corridor superimposed on the burn room energy supply.

2.5 Recommendations

It is still early to draw definite conclusions based on comparisons of single tests. Efforts are now being made to formulate a strong mathematical foundation by which these experiments may be used as verification for further development of the analytical procedures. In this manner the

trends developing during these experiments can be examined as tests of the mathematical models rather than as statistically oriented trends requiring expensive repetition before they can be accepted. Even if the results of these trends are accepted by those involved in the test work, statistically based conclusions have room for argument by those adversely affected by the findings. We are presently working on this problem in addition to developing the heat balance of the corridor.

As mentioned earlier, tests of four large cribs with only gypsum board in the corridor need to be run to establish a base line for the heat balance for all of the four crib tests shown in the table. Since several of the laboratory tests of carpet Sample No. 1 have shown a difference in its response to heat and flames with or without a pad, the next immediate test is planned to use this carpet placed on asbestos board without a pad.

A review of the Summary Table indicates the increase in crib weight might have been larger than needed; therefore, additional future tests will probably be planned with a fuel loading somewhat nearer to the three crib weight than to the 172 lbs total weight.

3.0 EMPIRICAL HEAT BALANCE CALCULATIONS

3.1

Currently a numerical program for corridor transient heat balance is performed semi-empirically to keep track of the energy in the entire corridor. The program separately itemizes the following terms, rate of heat release from the burning wood cribs, \dot{H}_B , rate of heat loss to the burn room, \dot{Q}'_B , rate of heat loss to the corridor, \dot{Q}'_C , heat transfer from burn room, \dot{Q}_B , rate of heat release due to combustible linings in corridor, \dot{H}_C , and finally \dot{Q}'_E the heat loss due to mass transport out the exhaust window.

Let \dot{M}_I be the rate of air flow in, \dot{M}_E the rate of gas flow out, and \dot{M}_C the rate of gaseous release in the corridor; a heat balance of the corridor yields the expression,

$$\dot{Q}_B + \dot{H}_C - \dot{Q}'_C - (\dot{M}_E \bar{C}_{PE} \bar{T}_E - \dot{M}_I C_{PI} T_I) = 0$$

Where bar indicates averaged quantities, T is temperature, C_p is the heat capacity and subscripts I and E indicates inlet and outlet.

In the above heat balance equation \dot{Q}_B is given by $\dot{H}_B - \dot{Q}'_B$. All heat loss terms are calculated semi-empirically from surface -temperature measurements. Having obtained all other terms empirically or semi-empirically one can then indirectly determine \dot{H}_C which is an important quantity characterizing the overall effect of the corridor lining materials.

3.2

An alternate simple heat balance calculation is also planned which may provide us with an ordering scheme of the fire hazard of various test conditions.

Defining $Q = \frac{\bar{T} - \bar{T}_B}{\bar{T}_B}$, and letting \bar{T} be the averaged corridor exhaust

temperature of a particular test configuration, and \bar{T}_B be the corresponding averaged temperature of a blank test (no combustibles in the corridor except the specified number of cribs).

The quantity Q is then an instantaneous normalized temperature expression which can serve as a means of gross relative energy evaluation for different tests. (Note in this gross relative energy evaluation, the detail effects of heat loss by conduction, convection and radiation pattern, the flow pattern in the corridor and the temperature dependence of C_p are all ignored.) This instantaneous quantity Q prior to flashover or its integral for a specific duration of the test up to flashover may serve as a practical evaluation of the relative hazardous nature of conditions tested.

For this scheme to work we must standardize our energy source. To achieve this standardization it seems that a gas flame may be more dependable than crib fires.

4.0 DISCUSSION OF POSSIBLE MATHEMATICAL APPROACHES

We are currently reviewing some recent literature on dynamics of the corridor fire. Due to the complexity of the corridor fire past research activities had been limited mostly to experimental observations with little or no analysis. The new literature under review shows a high degree of analytical activity on various aspects of fire research directly related to our corridor tests. It is hoped that in keeping with the current trend our experimental insights will also enable us to go into some mathematical modeling and analysis.

To participate in the current trend of applying analysis to fire research we may consider the following approaches.

4.1 Complete Mathematical Formulation

This is an attempt to formulate the corridor problem mathematically in its entirety and look for a complete numerical solution. This is an instinctive approach which has little chance of yielding useful results. A preliminary count turns up no less than 40 physical variables that need to be included in this approach. Furthermore many corridor dynamic phenomenon and their interactions are not well understood. Finally the amount of bookkeeping to keep track of the multi-regions in a corridor fire may be staggering. An attempt with this approach to study the corridor fire is yet to be seen.

4.2 Idealized Mathematical Formulations

This approach is best illustrated by one of the recent analytical papers in applied fire research titled "The Propagation of Fires in Passages Lined with Flammable Material" by Roberts and Clough.⁵ The problem of fire in a

long horizontal duct with constant ventilation was treated by a highly idealized mathematical model. Major assumptions that made the practical duct fire mathematically tractable are:

1. One dimensional heat balance in the direction of flame propagation, with conditions uniform across sections perpendicular to the direction of flame propagation. This completely rules out heat exchanges across the duct.
2. The duct is assumed to be infinitely long, and the velocity of flame propagation is assumed to be constant. With those two major assumptions the problem is transformed to a simple steady and stationary phenomenon.
3. Isothermal boundary conditions on the duct walls.
4. Rate of pyrolysis and heat loss coefficient (combined radiation and convection) are assumed to be constant and both processes are linear functions of temperature.

The duct fire was divided into three zones: the smoldering zone, the wood pyrolysis zone, and the preheating zone. The heat balance was applied to the wood pyrolysis zone. The heat balance as applied to a control volume of thickness dx where x is the only space coordinate in the problem contains the following terms:

1. Heat content of gas flowing into element dx .

2. Heat content of pyrolysis gas in element dx , due to surface temperature T_s .
3. Heat release due to combustible gas in element dx as measured by oxygen mass fraction change.
4. Heat loss through isothermal corridor walls.
5. Heat content of gases flowing out of element dx .

It is tempting to apply Roberts' and Clough's mathematical model to the corridor fire problem, but two major obstacles stand in the way: namely, the unsteady nature of the corridor flame, and conditions across the corridor are by no means uniform. However, before one gives up in despair additional idealization may be postulated to render the corridor problem more amenable to Roberts' and Clough's mathematical analysis.

First, partition of the corridor into an upper region and a lower region along a neutral plane and within each region conditions are assumed to be relatively uniform.

Second, we may consider only the fully developed corridor fire. In this case steady conditions may prevail.

With the above additional idealizations we may lose some generality but the prospect of obtaining a theoretical solution which will serve as an upper limit solution to the practical corridor fire is attractive. Of course,

it is also possible to apply Roberts' and Clough's model to the transient corridor fire problem by allowing a time dependent overall flame propagation velocity. A recent paper by DeRis titled "Duct Fires"⁶ reapplied Roberts' and Clough's model to the same problem but with some refinements. The essential improvements are: variation of gas temperature in the burned out zone and a more elaborate determination of heat loss to the duct walls. Some pertinent conclusions of DeRis are: gas temperature in preheating zone increases exponentially towards flame front, flame propagation velocity increases linearly with ventilation, heat loss to the duct wall is a significant factor, and heat of condensation of excess fuel is negligible.

4.3 Theoretical Phenomenological Studies of Important Local Phenomenons

Under this heading a number of current mathematical fire research analysis can be included.^{7,8,9,10,11,12} Under this classification, research efforts are directed towards isolated or local phenomenon of the overall building fire problem. For example in a series of four recent papers from FMRC the following local phenomenons were studied: pool burning⁷, and vertical fire plumes⁸, fire induced turbulent ceiling jet⁹, and ceiling fires.¹⁰ All of the above papers use phenomenological theory and result in simple correlation formulas with experiments rather than full analytical solutions. For example in the above pool burning and ceiling fire papers a simple phenomenological Ohm's law type mass transfer formula $\dot{m} = g B$ is assumed, where \dot{m} is the mass transfer rate, g is a surface conductance dependent on gas dynamic factors, and B is a dimensionless driving-force dependent on the thermodynamic properties of the main stream, of the fluid in contact with the phase boundary, and of the transferred substance. This

simple mass transfer phenomenological theory was first proposed by Spalding.¹³ Spalding's mass transfer model is briefly discussed in Appendix B. Later Kays¹⁴ suggested the term $g = \frac{\ln(1+B)}{B} \left(\int_0^Y \frac{dy}{\lambda} \right)^{-1}$ where Y is the flame thickness, and λ is the diffusion coefficient. The final form adopted by DeRis and Orloff is $\dot{m} = (\rho/c_p) S^{-1} B [\ln(1+B/B)]^n$ with $n = \frac{2}{3}$ for pool burning and $n = \frac{1}{3}$ for ceiling flame.

Other phenomenological theories are Hinkley's¹¹ Froude number analogy for ceiling smoke travel, and Thomas'¹² simple experimental correlation approach for movement of smoke against air flow. In Thomas' paper he arrived at the formula for smoke movement $U_c = K \left(\frac{g Q'}{\rho T_c} \right)^{\frac{1}{3}}$, where U_c is velocity of smoke movement, Q' is rate of entry of hot smoke and gases per unit width of a rectilinear corridor in units of heat, g is the gravitation constant, K is an empirical constant, and ρ , T , C are the conventional thermodynamic variables.

Analysis along these lines can be adopted to predict corridor ceiling flame and carpet flame propagations for example.

4.4 Equivalent Thermal Mass Approach

The generalized equivalent thermal mass concept has been used extensively in recent transient heat transfer calculations in an enclosure.^{15,16,17,18,19,20} A recent paper by Kusada et al, titled "Prediction of Indoor Temperature by Using Equivalent Thermal Mass Response Factors"²⁰, represents the highlight of research activities with this approach. In essence the approach treats a

building as a black box with lumped thermal properties. These "equivalent thermal mass response factors" can be determined both analytically or semi-empirically. With these "response factors" known, a simple heat balance is applied to the one cell enclosure with one temperature. This then results in a simple tractable ordinary differential equation which can be easily integrated. This approach seems very promising to the transient corridor problem. If the transient corridor fire can be conveniently divided into a finite number of interior cells as discussed in previous sections in this report application of the equivalent thermal mass approach may be feasible. Of course the feasibility of simple cell characterization of the corridor fire will be pending further experimentation as discussed under section 5.0 of this report.

5.0 RECOMMENDATION OF ADDITIONAL INSTRUMENTATION

In order to determine the neutral-density plane in the corridor, as Waterman did in rooms, we will have to place pitot tubes at more stations down the corridor, with at least three pitot tubes per station, midway between the walls and vertical from ceiling to floor. To determine the concentration of total combustibles above, below and at the neutral-density plane, at least three or more total combustible analyzers will be required at a station in the middle of the corridor. This arrangement would serve to test Waterman's conclusions as they may have some application to the corridor under conditions of natural convection.

For rigorous heat balance calculation and for the simplified mathematical representation, such as one similar to that of Roberts', applied to the corridor at least four pitot tubes on the burn room door and at least four in the window are needed to determine mass flow of air entering and leaving the corridor. The concentration of O_2 entering and leaving the corridor in each pitot quadrant should be monitored. In addition O_2 should be monitored above and below the neutral-density plane at various stations in the corridor. An important parameter in Robert's heat balance representation is the O_2 concentration available to the fuel supply in the corridor. Since uncombusted material enters and leaves the corridor this should be monitored by combustion analyzers at entrance and at exit of the corridor to make a direct evaluation of corridor material involvement.

To further test Waterman's conclusions on the temperature distribution under

natural convection conditions in a room as applied to the corridor and to do a simplified heat balance analysis patterned similar to that of Roberts it is necessary to have vertical strings of thermocouples at various stations down the corridor. It is further implied in the work of Waterman and others that near flashover, the radiant energy emitted from the upper walls and the ceiling (even when noncombustible) are a major energy factor in contributing to flashovers. Therefore to compare the corridor ceiling radiant energy to that obtained by other workers during the fire buildup and at and near flashover it is advisable to have radiometers at various stations on the floor facing the ceiling.

This in general is the type of instrumentation needed to:

Compare the corridor fire behavior under various conditions with the results in the literature.

To interpret in a quantitative experimental manner the corridor thermal and fire behavior during the various phases of the fire.

To do an accurate heat balance.

To phenomenologically characterize.

To establish a reasonable base for assumptions needed for a theoretical analysis of corridor thermal and combustion behavior.

To experimentally verify the accuracy of representation of any theoretical analysis of the corridor.

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APPENDIX A

Peak Heat Release Value

The peak heat release values were calculated by multiplying the observed rate of weight loss, lb/min, of the cribs by the heating value of the wood.

The heating value of the wood was calculated by modifying oxygen bomb values of 8000 Btu/lb. The modification included an allowance for the moisture content as a weight allowance and in the heat of vaporization at 75 °F is 1051 Btu/lb and the change in enthalpy from 212 °F and 1100 °F is 520 Btu/lb; thus the total heat needed to vaporize the moisture from 75 °F to 1100 °F is assumed to be 1580 Btu/lb.

The rate of heat release, Btu/min, is then calculated from the following:

$$H_c = .9W \times H_{OB} - .1W \times \Delta h$$
$$= 7100 W$$

where

H_c = rate of heat release, Btu/min

W = rate of weight loss of wood burned (measured to contain approximately 10% moisture during these test, lb/min.)

H_{OB} = heating value as found from oxygen bomb tests, Btu/lb

Δh = change in enthalpy of the water vapor from 75 °F to 1100 °F, calculated to be 1580 Btu/lb.*

* Keenan & Kayes Steam Tables

The peak heat release rates then become:

Test 323 (low value, 3 cribs) - $H_c = 7100 \times 1.97 \times 3 = 39,900$ Btu/min

Test 324 (high value, 3 cribs) - $H_c = 7100 \times 3.37 \times 3 = 71,700$ Btu/min

Test 330 (low value, 4 cribs) - $H_c = 7100 \times 1.37 \times 4 = 38,900$ Btu/min

Test 334 (high value, 4 cribs) - $H_c = 7100 \times 4.5 \times 4 = 127,600$ Btu/min

APPENDIX B

Spalding's Local Mass Transfer Modeling Relations Applied to Fires

The process contributing to mass-transfer flux, defined as the net rate of material transfer per unit area of interface from the so called neighboring phase into the considered phase, lb/ft^2 , are often numerous. Spalding¹³ assumed that the processes at the interface or surface are such, that the result can be lumped as though the result is a single phenomenon assuming mass conservation and steady-flow of energy. Hence certain relations exist between the transport properties of the fluid contact with the phase boundary and the transferred substance of every mass transfer problem, including those with simultaneous heat transfer and chemical reaction, such that the result can be expressed by relations in the form of "Ohn Law" are shown

$$\dot{m}'' = g B$$

where

\dot{m}'' = the mass-transfer flux through the surface

g = a surface conductance term which is a function of the aerodynamics of the system

B = a dimensionless driving-force dependent on the thermodynamic properties of the bulk fluid in contact with the phase boundary and of the transferred substance.

The surface conductance term g has been shown by Spalding^{13,21} to be related to a surface conductance term g_{heat}^* from heat transfer theory

where the mass transfer rate is assumed small, by the following relation:

$$g = g_{\text{heat}}^* \frac{\ln(1+B)}{B}$$

The advantage of this relation is that g_{heat}^* can be calculated from heat transfer data which is available. For example for the turbulent boundary layer problem where the interface is an external isothermal surface of a two dimensional body with the considered phase flowing over it forming a turbulent boundary layer. Then the g_{heat}^* (from heat transfer data) is the following:

$$g_{\text{Heat}}^* = \frac{0.0288 G}{N_{\text{Pr}}^{2/3}} \left[\frac{\mu}{\int_0^x G dx} \right]^{0.2}$$

where N_{Pr} is the Prandtl Number and

G is the local mass velocity ($P_G V_G$) just outside the boundary layer as a function of the distance X along the surface in the flow direction ($\text{lb/ft}^2\text{h}$).

Therefore for any particular surface and stream shape, it can be shown from dimensional analysis with certain assumptions that the solution to any forced-convection mass transfer problem with the considered and neighboring phases having uniform states that the following relation exist:

$$\dot{m}'' = G f(B, \frac{G l}{\mu_0}, \frac{\mu_0}{r_0})$$

where

G = the mass velocity of the fluid at entry

l = a configuration dimension

μ_0 = the fluid viscosity is a reference state

r_0 = an exchange coefficient of the relevant conserved property P

where

$$B = \frac{P_G - P_S}{P_S - P_T}$$

Subscript G indicates considered phase

S indicates solid surface

T indicates neighboring phase

$\frac{G\lambda}{\mu_0}$ is a Reynolds number

$\frac{\mu_g}{\gamma_s}$ is a Prandtl or Schmidt number depending on the nature of the conserved property appearing in B.

The Ohm's Law type treatment of Spalding may be applicable to the corridor in examining a local area of the floor material or ceiling material, where the driving force B for the floor or ceiling material in respect to the oxygen content of the air, can be related to the measured mass-transfer flux in that given local area and the local aerodynamics of the corridor fire via g_{heat}^* for forced convection where g_{heat}^* would be determined from temperature and pitot tube measurements in the local area of consideration. The values of B could be determined under laboratory conditions for various materials and oxygen concentrations. Also g_{heat}^* could be found under other model corridor and chamber conditions and compared to the results of the full scale corridor. For example DeRis and Orloff^{7,10} have applied the Spalding model to liquid pool burning fires under extensive turbulent conditions concluded that a mass-transfer flux \dot{m}'' equation of the following general form applied:

$$\dot{m}'' = (\lambda/c_p)_B \left[0.15 \left(\frac{g(\rho_g - \rho_s)}{\gamma_r \alpha_r \rho_r} \right) \right]^{\frac{1}{3}} B \left[\frac{\ln(1+B)}{B} \right]''$$

where $\rho_g - \rho_f$ is the density difference between the ambient air and the flame gases.

ν_r is the gas phase kinematic viscosity.

α_r is the gas phase thermal diffusivity.

ρ_r is the gas phase density.

λ is the thermal conductivity of the gas.

C_p is the specific heat of the gas.

B again is the mass transfer driving force in this case being of the following form:

$$B = \frac{Y_{O_2} Q}{M_o \nu_o' L} - \frac{C_p (T_s - T_g)}{L}$$

where Y_{O_2} is the oxygen concentration in the ambient air in the local area.

Q is the heat of combustion of the material under the above oxygen concentration reaction condition.

M is the molecular weight of oxygen.

ν_o' is the stoichiometric coefficient relating mass of oxygen consumed per mass of material $(T_s - T_c)$ the temperature difference between the material surface and the ambient gas.

L is the effective heat of vaporization of the material evaluated under lab conditions where $L = \dot{q}'' / \dot{m}''$.

\dot{q}'' is the heat flux measuring the heat transfer between the material surface and the ambient air given as follows:

$$\dot{q}'' = \frac{\lambda}{\delta} (T_g - T_s)$$

where λ is the gaseous thermal conductivity

T_G is the ambient gas temperature

T_s is the material surface temperature

δ is the flame layer thickness

where:

$$\delta = \left[\frac{0.15 - q(\rho_s - \rho_g)^{\frac{1}{3}}}{r_r \alpha_r \rho_r} \right]^{-1}$$

FIG. 1 LOAD CELL DATA (3 CRIBS)

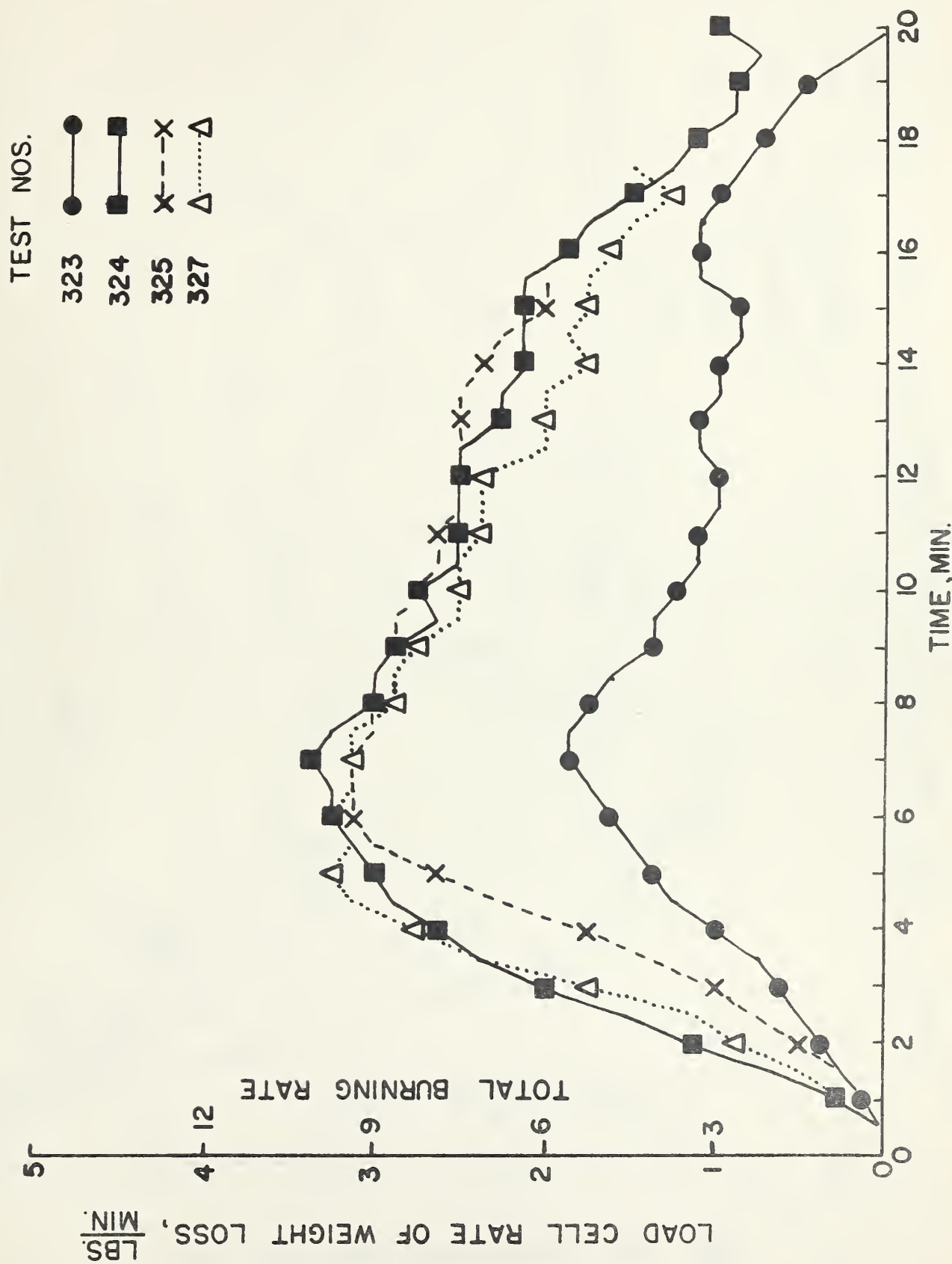
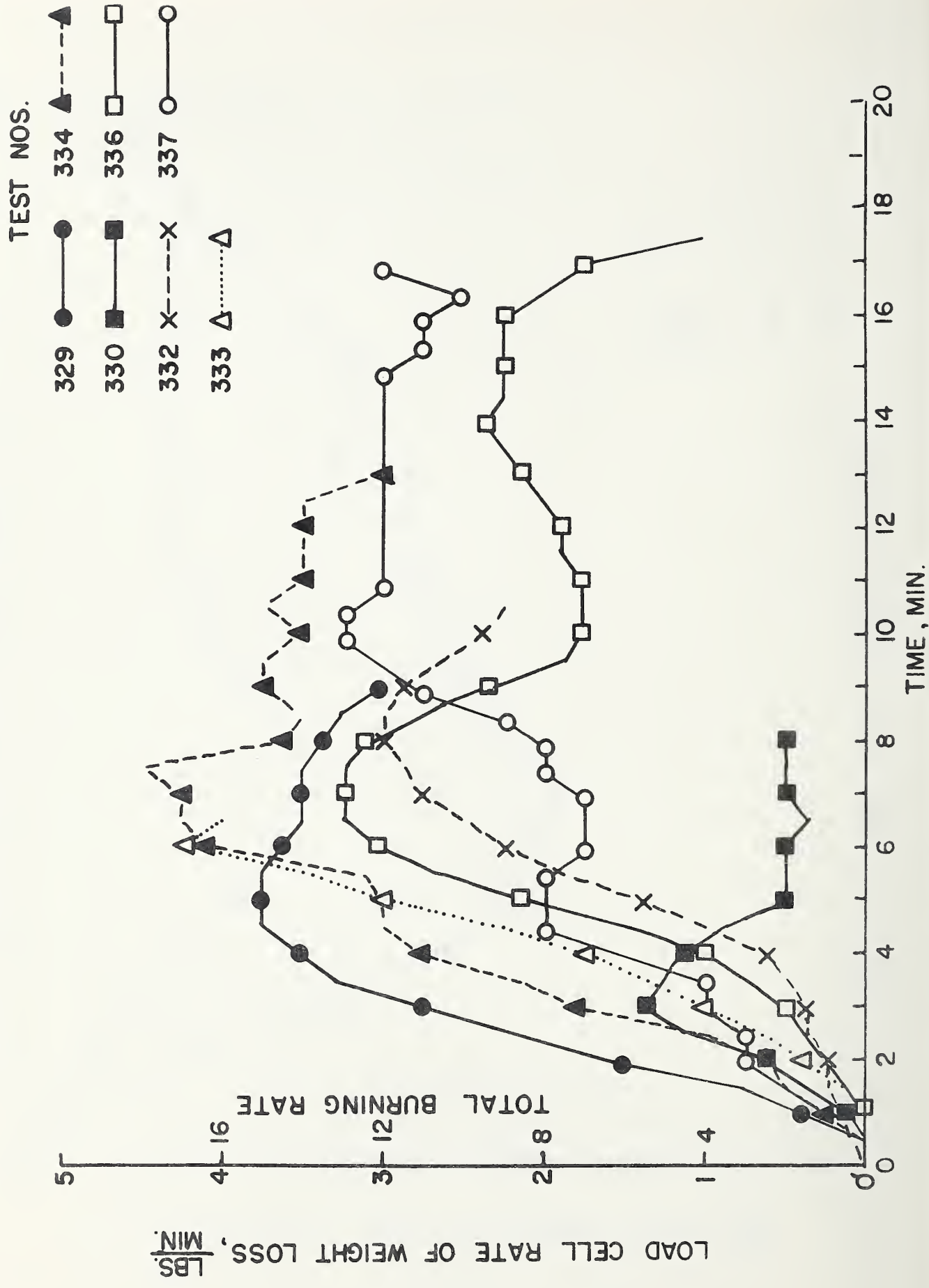


FIG.2 LOAD CELL DATA (4 CRIBS)



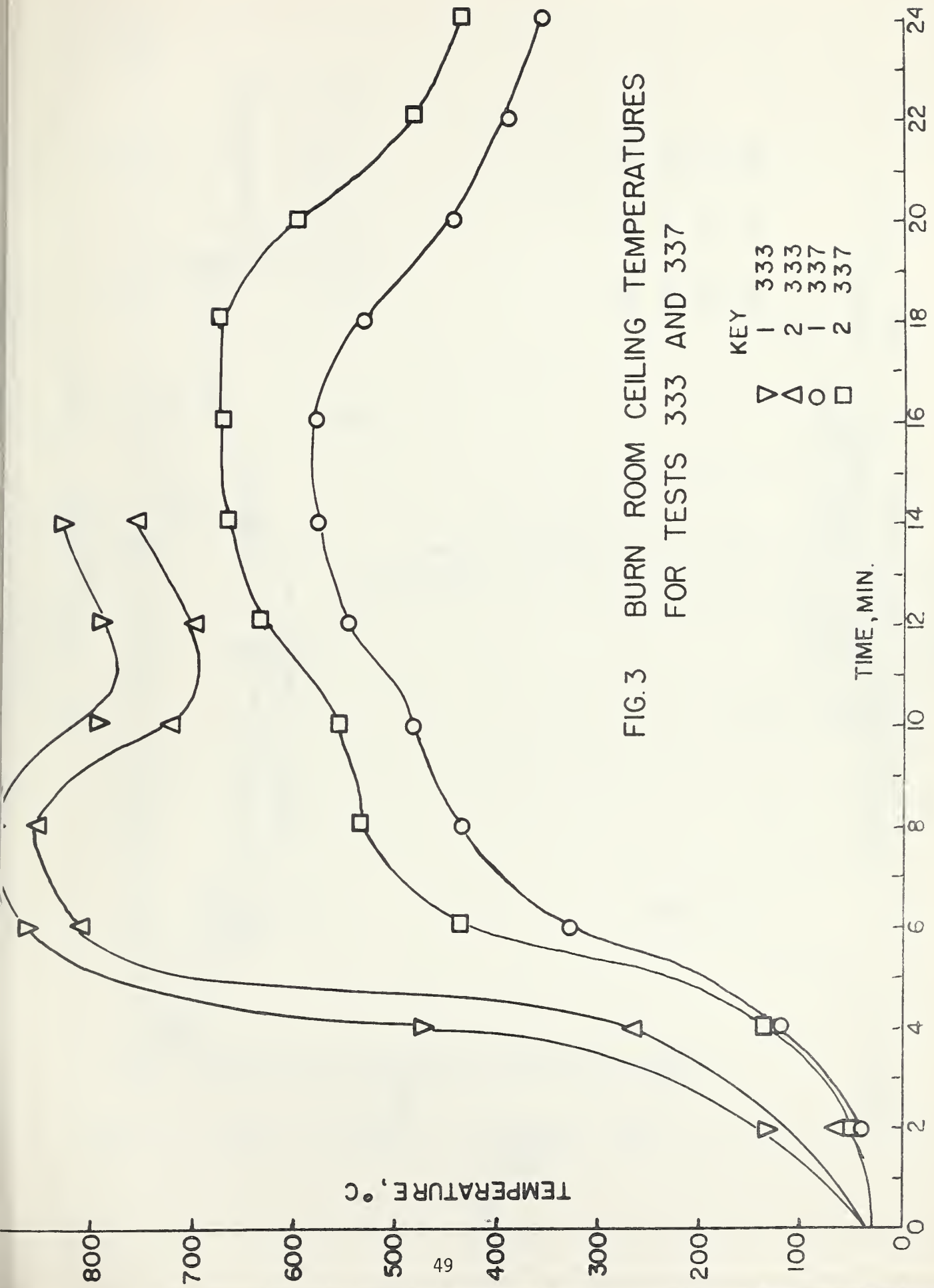
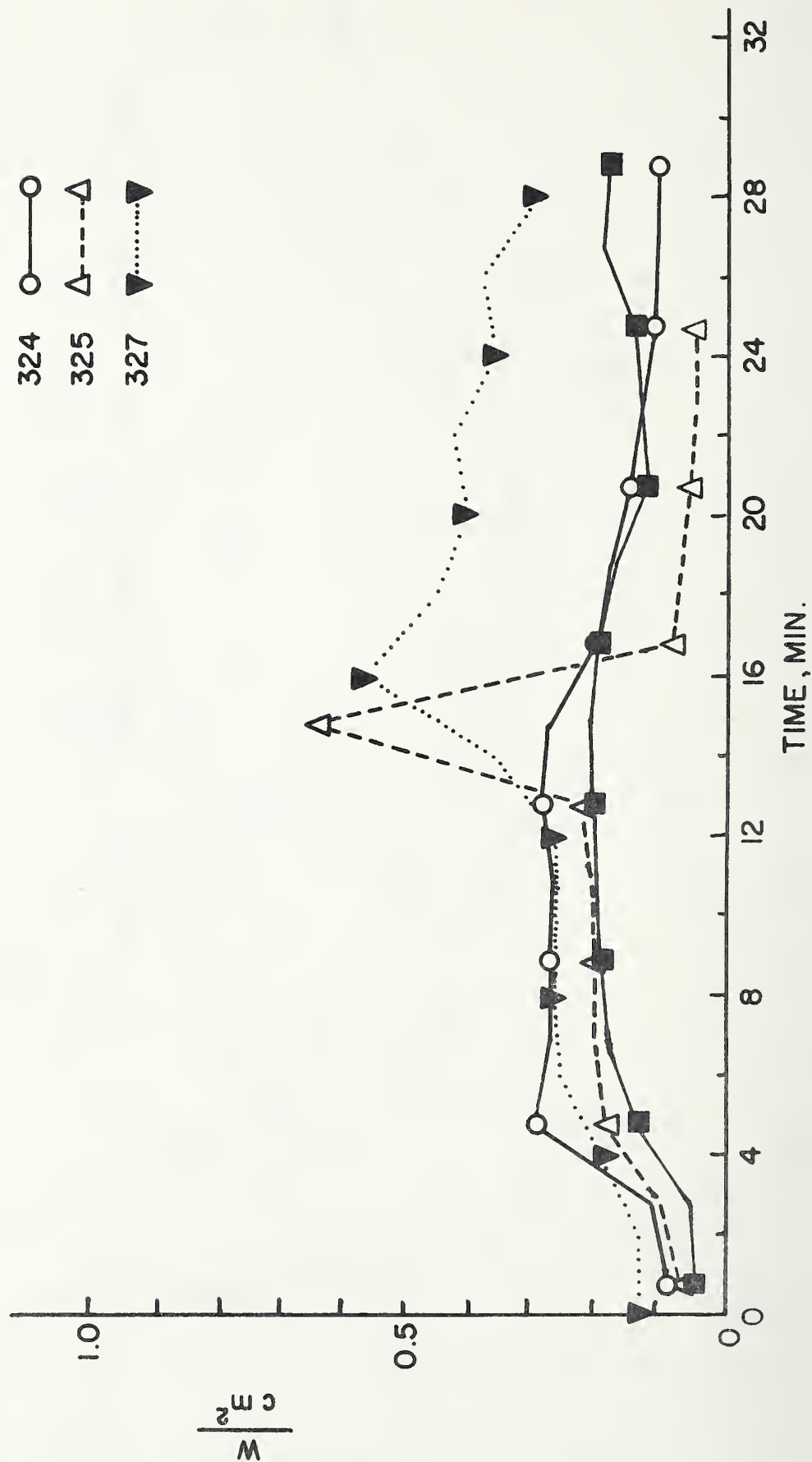


FIG.3 BURN ROOM CEILING TEMPERATURES
FOR TESTS 333 AND 337

FIG. 4 RADIOMETER READING VS. TIME
(R1: CORRIDOR FLOOR C IN FRONT
OF BURN ROOM DOOR.)

- 323 \blacksquare — \blacksquare
 324 \circ — \circ
 325 \triangle --- \triangle
 327 \blacktriangledown \blacktriangledown



(R1: CORRIDOR FLOOR ϕ IN FRONT
OF BURN ROOM DOOR.)

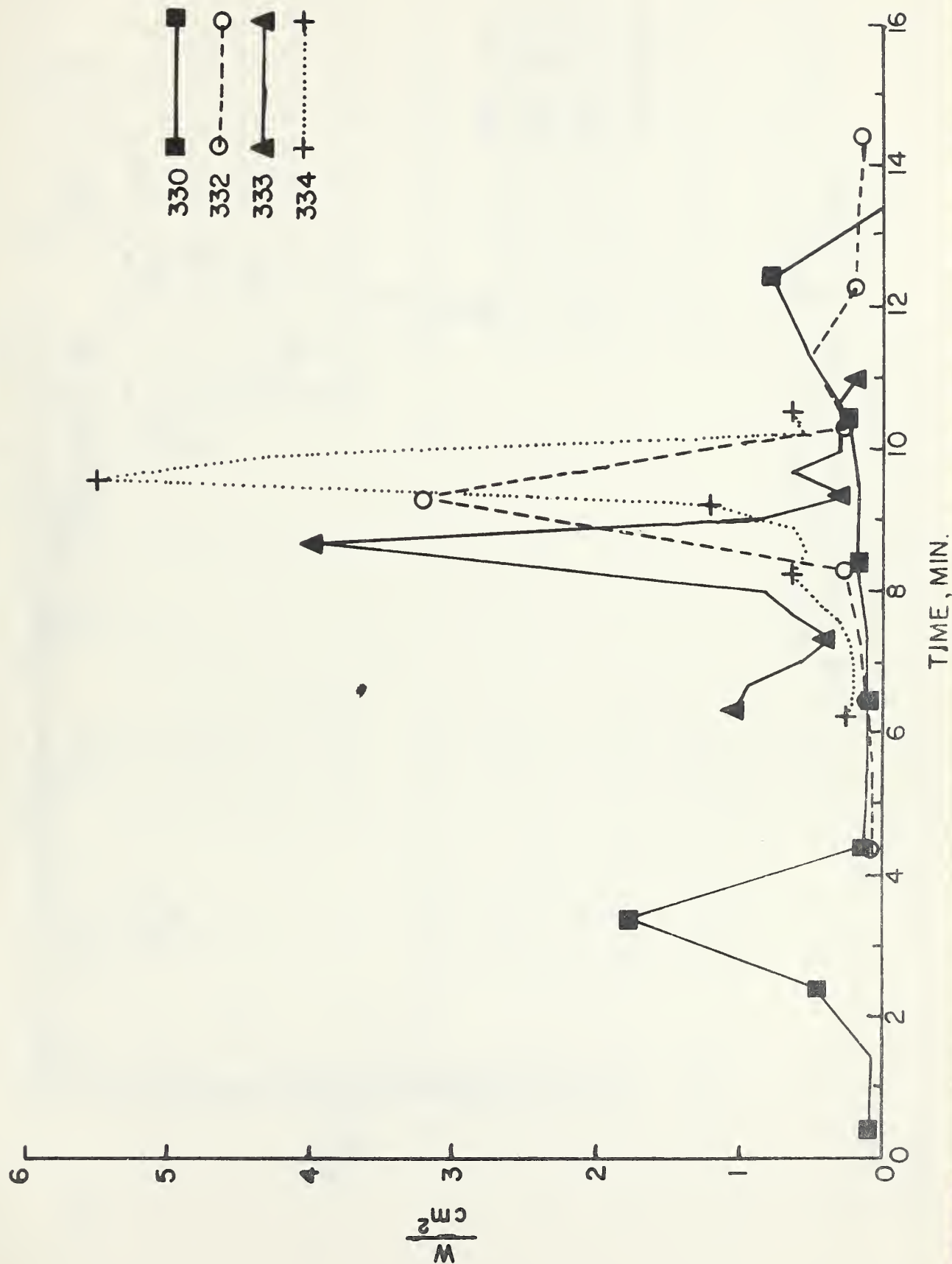


FIG. 6 RADIOMETER READING VS. TIME
(R4: CORRIDOR FLOOR $\frac{1}{2}$ TWO-
THIRDS DOWN AT 21 FEET.)

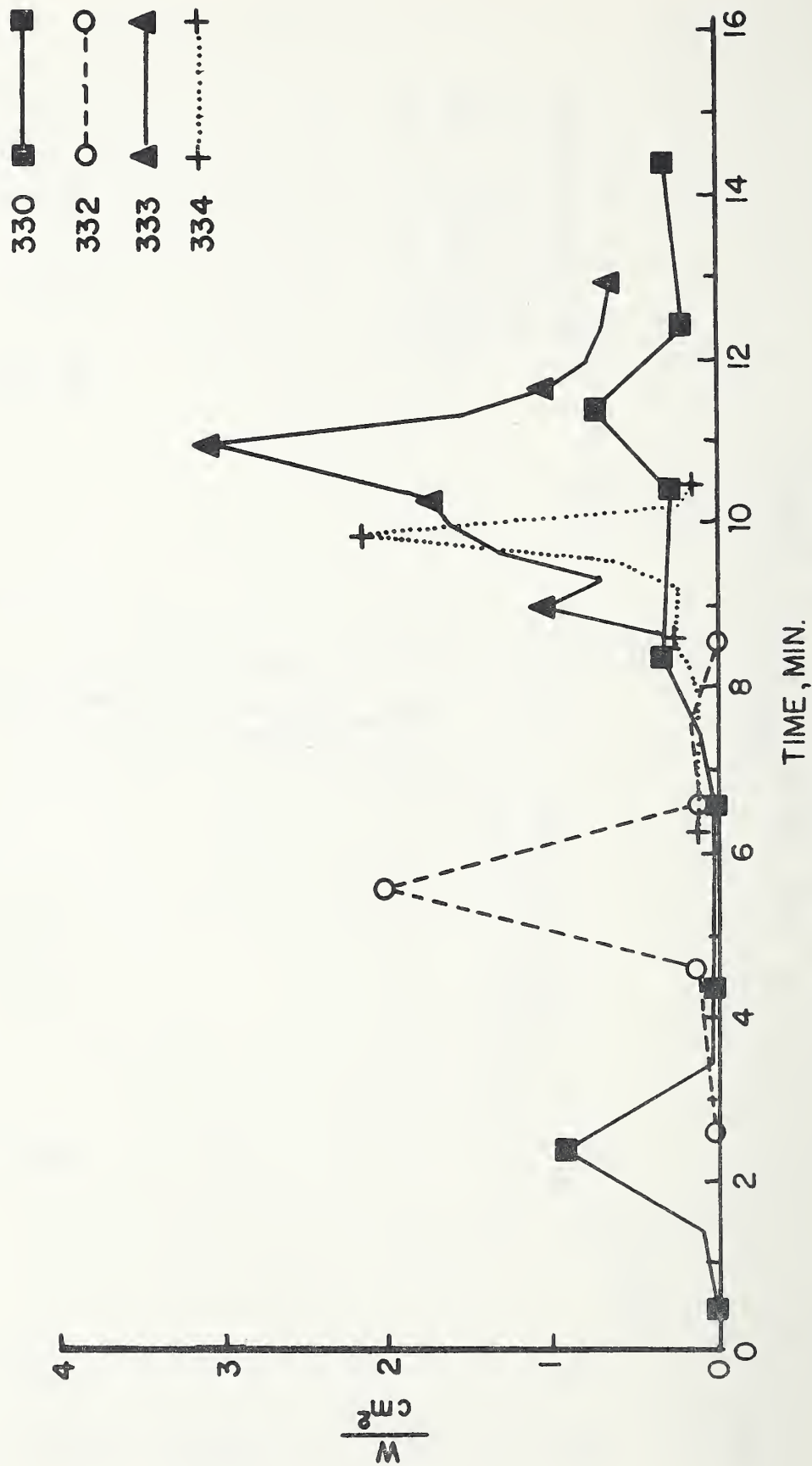


TABLE 1

CORRIDOR

TEST SUMMARY TABLE

TEST NUMBER	CONDITIONS -- WITH GYPSUM BOARD WALLS	CORRIDOR FLOOR	BURN ROOM FIRE LOAD	FORCED AIR SPEED, MPH	PEAK FLOOR RADIOMETER VALUE, (1) w/sq-cm	TIME FLAMES OUT OF WINDOW, Min:Sec	COMMENTS AND OBSERVATIONS
321	Gypsum board	Brick	1-25 lb crib	1-2 ⁽²⁾	0.07	No flames	Data collected for later comparisons
322	Gypsum board	Brick	1-54 lb crib	1-2	0.12	No flames	Crib burned at a higher burning rate (10 ⁴ Btu/m)
323	Gypsum board	Brick	3 cribs, 133 lb total weight	1-2	0.30	No flames	Heat balance calculations show about 80% crib heat flows out of burn room to corridor
324	Celotex, Flame ³ Spread 74	Brick	3 cribs, 133 lb total weight	1-2	0.22	No flames	Some flaming of ceiling adjacent to burn room door noted 23 min after ignition of cribs
325	Celotex, Flame Spread 222	Brick	3 cribs, 133 lb total weight	1-2	0.55	14:00	Ceiling commenced burning 14 min after ignition
327	Celotex, Flame Spread 222 on 1st 8 ft & Flame Spread 74 on remainder	Brick	3 cribs, 126 lb total weight	1-2	0.58	No flames	First 8 ft of ceiling burned 12 min after ignition, with flashes down to 20 ft.
329	Particle (chip) board, Flame Spread 120	Brick with patches of sample no. 1 rug on floor	4 cribs, 172 lb total weight	1-2	1.23	12:00	Ceiling burned over 12 min after ignition; patches of rug smoldered without burning
330	Chip board, Flame Spread 120	Sample no. 1 rug & pad (wall-to-wall)	4 cribs, 172 lb total weight	0	1.80	2:55	Burning in corridor air occurred within 2½ min after crib ignition (ceiling ignited 2:30; floor ignited 2:35); flame velocity=72 ft/min, floor and ceiling traverse time 25 sec.
332	Chip board, Flame Spread 120	Brick with patches of sample no. 1 rug & pad	4 cribs, 172 lb total weight	0	3.22	10:50	Voluminous burning at ceiling 9 min 20 sec after ignition; rug patch 1 ft 8 in down corridor commenced burning at 10 min 15 sec; flame velocity = 20 ft/min, traverse time 1:30.
333	Gypsum board	Sample no. 1 rug & pad (wall-to-wall)	4 cribs, 172 lb total weight	0	4.00	12:40	Flaming in corridor air 6 min after ignition; fire on corridor rug 7-5/4 min after ignition. Carpet flame velocity 6 ft/min, traverse time 5 min.
334	Chip board, Flame Spread 120	Sample no. 1 rug & pad (wall-to-wall)	4 cribs, 172 lb total weight	1	5.4	9:20	Carpet in burn room in flames 5½ min after ignition of cribs; violent burning in corridor gases occurred 9 min 20 sec after ignition
335	Gypsum board	Varnished Oak	4 cribs, 172 lb total weight	0	10.4	8:50	Slow burning in corridor air 5 min after ignition; flames still at doorway 5½ min after ignition, until flames spread to window in 8:50
336	Gypsum board	Vinyl Tile	4 cribs, 160 lb total weight	0	8.90	No flames out of window	Gypsum paper burning 5:50 after ignition; flames on floor outside door at 6:50; flames on floor down to 10 ft distance at 8:40

¹Located in corridor floor, four feet on perpendicular line from burn room doorway.

²Corridor air draft varied from 5200 to 6200 cfm in air condition duct.

³Flame Spread as determined by ASTM E162 Radiant Panel Test.



